



Practical Course Of Physical chemistry

Prepared by

A.L. Karzan Abdulkareem Omar

Contents:

Experiment (1): Determine the Density of Liquids and Solids.

Experiment (2) : Determine the surface tension of liquid by capillary rise method.

Experiment (3): Determine the viscosity of a given liquid by Ostwald's viscometer.

Experiment (4): Determine the radius of a molecule by viscosity measurements.

Experiment (5): Determine the molecular weight of a high polymer by viscosity measurements e.g. (polystyrene).

Experiment (6): Determine the specific and molar refraction of a given liquid by Abbe refractometer.

Experiment (7): Determine molecular weight by boiling point elevation

Experiment (8): Determine Molecular Weight by the Dumas Method

Experiment (9): Determine the heat of solution of oxalic acid from solubility in water at different temperature.

Experiment (10): Determine the solubility of benzoic acid in water at different temperature and hence its heat of solution.

Some basic concepts

In experiment of chemistry, mostly students require standard solution to study physical properties.

Standard solution:

A solution of known concentration is called standard solution. It contains a known weight of substance in a definite volume of solution. Generally concentrations are expressed in terms of

- i) **Normality:** It is the number of gram equivalents of solute present in one liter of solution.

$$\text{Normality (N)} = \frac{\text{Number of gram equivalents}}{\text{Liter of solution}}$$

- ii) **Molarity:** It is the number of moles of solute present in one liter of solution.

$$\text{Molarity (M)} = \frac{\text{Number of moles}}{\text{Liter of solution}}$$

- iii) **Molality:** It is the number of moles of solute dissolved in 1000 gms of solvent.

$$\text{Molality (m)} = \frac{\text{Number of moles of solute}}{\text{Wt. of solvent in kg (1000 gms)}}$$

- iv) **Mole fraction:** The mole fraction of a component in a solution is defined as the number of moles of that component divided by the total number of moles of all components in the solution. If a solute is dissolved in solvent then

$$\text{The mole fraction of solute} = \frac{\text{Moles of solute}}{\text{Moles of solute} + \text{Moles of solvent}}$$

$$\text{The mole fraction of solvent} = \frac{\text{Moles of solvent}}{\text{Moles of solute} + \text{Moles of solvent}}$$

- v) **Volume fraction:** If two liquids are miscible to form a solution then the volume fraction can be determined as follows:

$$\text{Volume fraction of one (V}_1\text{)} = \frac{V_1}{V_1 + V_2}$$

$$\text{Volume fraction of other (V}_2\text{)} = \frac{V_2}{V_1 + V_2}$$

- vi) **Weight fraction:** It is the ratio of weight of solute to the total weight of solution.

$$\text{Wt. fraction of solute} = \frac{\text{Wt. of solute}}{\text{Total wt. of solution}}$$

$$\text{Wt. fraction of solvent} = \frac{\text{Wt. of solvent}}{\text{Total wt. of solution}}$$

If weight fraction multiplied by 100 it is termed as percentage by weight.

- vii) **Percentage weight of solute by volume of solvent:** It is the weight of solute dissolved in 100 ml of solution: (Wt/V) and (Wt/Wt). also there is percentage volume of solute by volume of solvent (V/V).

- viii) **Parts per thousand (P.P.T.):** This is a method of expression concentration of solute if solution is sufficiently dilute.

If 20 gm of can sugar is dissolved in 1000 gm of water (or 1000 ml) then the resultant solution is said to be 20P.P.T. it can be expressed as
 $\text{P.P.T} = \text{gm}/1000 \text{ gm of solution}.$

- ix) **Parts per thousand (P.P.m.):** This is the best method of express concentration of solute when solution is expected to be very dilute.

If 20 gm of can sugar is dissolved in one million gm of water (or 1000 ml) then the resultant solution is called 20 P.P.m. it can be expressed as

$$\text{P.P.m} = \text{gm}/1000000 \text{ gm of solution.}$$

- x) **Strength of solution:** The strength of solution is always expressed in terms of grams per liter.

If the concentration is given in terms of normality then

$$\text{Strength} = \text{Normality} \times \text{Equivalent wt.}$$

And if the concentration is given in terms of molarity then

$$\text{Strength} = \text{Molarity} \times \text{Molecular wt.}$$

- xi) **Dilution:** A solution is diluted when extra solvent is added. The concentration of dilute solution can be calculated by using this equation which known as Dilution law

$$M_1 V_1 = M_2 V_2 \text{ Or } N_1 V_1 = N_2 V_2.$$

Preparation of solution

1) Preparation solution from solid material

$$Wt_{(gm)} = \frac{M \times V_{ml} \times M.wt}{1000}$$

For example:

prepare 0.1 M of NaOH in 100 ml of distilled water.

M.wt of NaOH = 23+16+1= 40 gm/mol

V = 100 ml

M = 0.1 M

Wt = ?

$$Wt_{(gm)} = \frac{M \times V_{ml} \times M.wt}{1000} = \frac{0.1 \times 100 \times 40}{1000} = 0.4 \text{ gm}$$

Take 0.4 gm of NaOH and dissolved in quantity of water, when it dissolved completely add it into 100 ml standard flask and fill it up to the mark.

For example:

Prepare 0.1 N of Ca(OH)_2 in 100 ml of distilled water.

$$\text{Eq.wt of } \text{Ca(OH)}_2 = \text{M.wt} / 2 = 74/2 = 37 \text{ gm / mol}$$

$$V = 100 \text{ ml}$$

$$N = 0.1 \text{ N}$$

$$W_t = ?$$

$$W_t \text{ (gm)} = \frac{N \times V_{\text{ml}} \times \text{Eq.wt}}{1000} = \frac{0.1 \times 100 \times 37}{1000} = 0.37 \text{ gm}$$

Take 0.37 gm of Ca(OH)_2 and dissolved in quantity of water, when it dissolved completely add it into 100 ml standard flask and fill it up to the mark.

2) Preparation solution from liquid material

For preparation of dilute solution from concentrate liquid can be use these information. Density, % and M.wt or Eq.wt.

$$\text{Sp.gr} = \frac{\text{Density of liquid}}{\text{Density of water at } 4^{\circ}\text{C}}$$

Density of water at $4^{\circ}\text{C} = 1$, i.e. $\text{Sp.gr} = \text{Density}$

% is the percentage of concentrate liquid in bottle.

$$M = \frac{\text{Sp.gr} \times \% \times 1000}{\text{M.wt}} \quad \text{Or} \quad N = \frac{\text{Sp.gr} \times \% \times 1000}{\text{Eq.wt}}$$

By using dilution law:

$$M_1 V_1 = M_2 V_2 \quad \text{Or} \quad N_1 V_1 = N_2 V_2$$

For example:

Prepare 0.5 M and N of H_2SO_4 in 100 ml of distilled water. If you know density of concentrate $\text{H}_2\text{SO}_4 = 1.84 \text{ gm/ml}$, M.wt= 98 gm/mol and % = 96.

$$M = \frac{\text{Sp.gr} \times \% \times 1000}{\text{M.wt}} \quad \text{for} \quad N = \frac{\text{Sp.gr} \times \% \times 1000}{\text{Eq.wt}}$$

$$= \frac{1.84 \times 96/100 \times 1000}{98} \quad \text{for} \quad = \frac{1.84 \times 96/100 \times 1000}{98/2}$$

$$= \frac{1.84 \times 0.96 \times 1000}{98} \quad \text{for} \quad = \frac{1.84 \times 0.96 \times 1000}{49}$$

$$M = 18.02 \quad \text{for} \quad N = 36.04$$

Now, for Prepare 0.5 M and N of H₂SO₄ in 100 ml of distilled water, using dilution law.

$$M_1 V_{1(\text{conc})} = M_2 V_{2(\text{dilute})}$$

for

$$N_1 V_{1(\text{conc})} = N_2 V_{2(\text{dilute})}$$

$$18.02 \times V_{1(\text{conc})} = 0.5 \times 100$$

for

$$36.04 \times V_{1(\text{conc})} = 0.5 \times 100$$

$$V_{1(\text{conc})} = 2.77 \text{ ml}$$

$$V_{1(\text{conc})} = 1.38 \text{ ml}$$

Take calculated volume of concentrate liquid and put it in standard flask fill up to the mark by distilled water.

Experiment (1)

Determine the Density of Liquids and Solids

Apparatus:

Beaker, density bottle or Pycnometer, ...etc.

Chemicals:

Irregular solid powder, Irregular and regular wood, benzene and water.

Theory:

Density is defined as the mass per unit volume of a substance, and it is a physical property of matter. A physical property can be measured without changing the chemical identity of the substance. Since pure substances have unique density values, measuring the density of a substance can help identify that substance. Density is determined by dividing the mass of a substance by its volume:

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

The units of density are commonly expressed as g/cm³ for solids, g/mL for liquids, and g/L for gases.

Density is also an intensive property of matter. This means that the value of density is independent of the quantity of matter present.



Fig. 1 pycnometer or density bottle

A) Determine the density of water and benzene

Procedure:

1. By using the electronic balance, weight empty density bottle (W_1) with its caps.
2. Fill the density bottle up to neck by distilled water and weight it (W_2).
3. Find the weight of water (W_3).
4. Density bottle has known volume (V).
5. Calculate Density of water.
6. Repeat same steps to find the density of benzene.

Calculation:

$$\text{Density} = \frac{W_3}{V}$$

$$W_{3(\text{weight of liquid})} = W_{2(\text{weight of density bottle with liquid})} - W_{1(\text{weight of empty density bottle})}$$

V is known volume of density bottle

B) Determine the density of an irregular solid

Procedure:

1. Weight the irregular solid on a balance (W).
2. Fill the Measuring Cylinder with Water to a known Volume (V_1).
3. Add the irregular solid to cylinder, record the increase level of water (V_2).
4. Find the volume of an irregular solid ($V = V_2 - V_1$).
5. Calculate the density of an irregular solid.

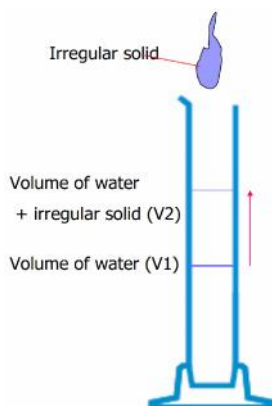


Fig.2 Irregular solid

OR use a Eureka Can to find the Volume.

Procedure:

1. Weight of the irregular solid on a balance.
2. Add water until just overflowing.
3. Place a Measuring Cylinder under the spout.
4. Add the irregular solid to Eureka Can.
5. Collect the Water and read off the Volume.
6. Calculate density of an irregular solid.

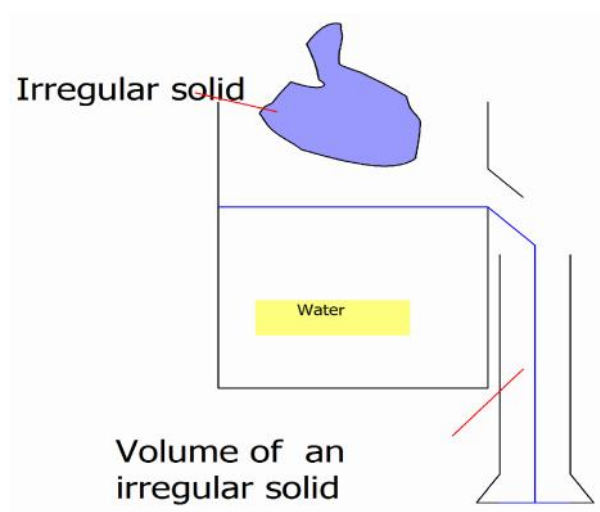


Fig. 3 Eureka Can

C) Determine the density of regular solid

Procedure:

1. Weight the regular solid on a balance.
2. Measure the three lengths and calculate the Volume.

(ie $V = l \times w \times h$)

3. Calculate the density of a regular solid.

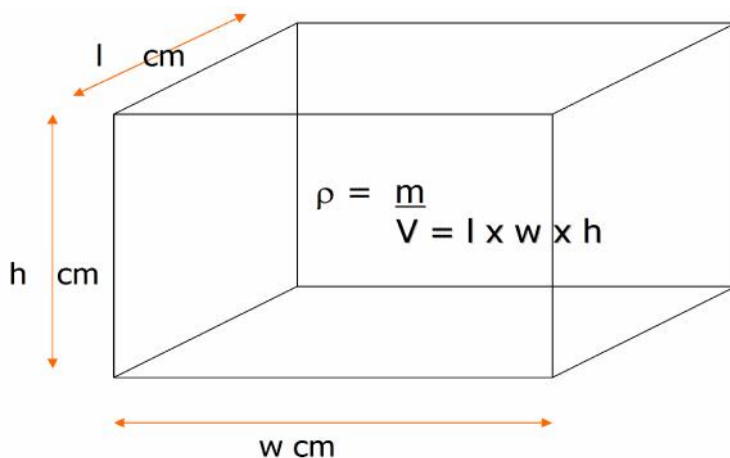


Fig. 4 Regular solid

Experiment (2)

Determine the surface tension of liquid by capillary rise method

Apparatus:

Capillary tube and beaker.

Chemicals:

Benzene, acetone and water.

Theory:

SURFACE TENSION [] is the force per unit length that must be applied parallel to the surface so as to counterbalance the net inward pull and has the units of dyne/cm or N/m.

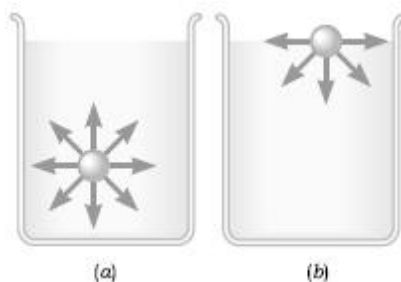
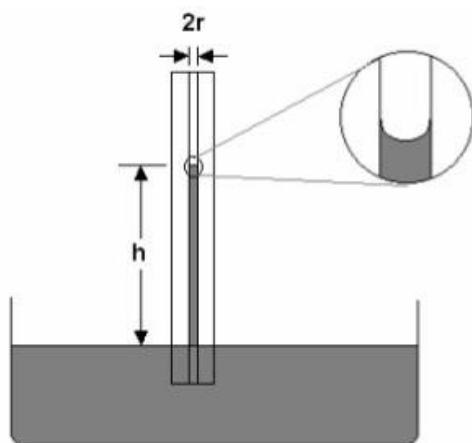


Figure. 5

Figure 5. (a) A molecule within the bulk liquid is surrounded on all sides by other molecules, which attract it equally in all directions, leading to a zero net force. (b) A molecule in the surface experiences a net attractive force pointing toward the liquid interior, because there are no molecules of the liquid above the surface.

Figure 5 illustrates the molecular basis for surface tension by considering the attractive forces that molecules in a liquid exert on one another. Part *a* shows a molecule within the bulk liquid, so that it is surrounded on all sides by other molecules. The surrounding molecules attract the central molecule equally in all directions, leading to a zero net force. In contrast, part *b* shows a molecule in the surface. Since there are no molecules of the liquid above the surface, this molecule experiences a net attractive force pointing toward the liquid interior. This net attractive force causes the liquid surface to contract toward the interior until repulsive collisional forces from the other molecules halt the contraction at the point when the surface area is a minimum. If the liquid is not acted upon by external forces, a liquid sample forms a sphere, which has the minimum surface area for a given volume. Nearly spherical drops of water are a familiar sight, for example, when the external forces are negligible.



Capillary rise due to surface tension.

Figure.6

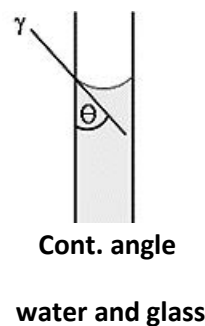


Figure.7

When a capillary tube is placed in a liquid, it rises up the tube a certain distance. By measuring this rise, it is possible to determine the surface tension of the liquid. It is not possible, to obtain interfacial tensions using the capillary rise method.

- i) Cohesive force is the force existing between like molecules in the surface of a liquid
- ii) Adhesive force is the force existing between unlike molecules, such as that between a liquid and the wall of a glass capillary tube

When the force of Adhesion is greater than the cohesion, the liquid is said to wet the capillary wall, spreading over it, and rising in the tube.

The upward force: Due to surface tension of the liquid at any point given by:

$$\text{Upward force} = 2 \cos \theta \quad r$$

Where, γ is surface tension, r is radius and θ = the contact angle between the surface of the liquid and the capillary wall.

The downward force: Due to gravity force given by:

$$\text{Downward force} = g h d \quad r^2 \cos \theta$$

Where, g is acceleration, h is height of liquid in capillary tube and d is density of liquid.

At Maximum height, the opposing forces are in equilibrium:

$$2 \cos \theta \quad r = g h d \quad r^2 \cos \theta$$

$$= \frac{1}{2} h g d r$$

Procedure:

1. Clean a capillary tube with water and acetone, dry it.
2. Prevent bubbles to form in capillary tube.
3. Immersed part of a capillary tube in water bath.
4. Suck up water with help of rubber pipe which attached to capillary tube.
5. Water will be rise through capillary tube and stabilized at specific height.
Measure this high by ruler and record it.
6. Measure the surface tension of water at room temperature 25°C, 30°C and 35°C.
7. Measure the surface tension of benzene at room temperature.

Calculation:

$$= \frac{1}{2} h g d r$$

is surface tension of liquid

h is capillary rise

g is acceleration

d is density of liquid

r is radius of capillary tube (0.045 cm).

Q/ Explain effect of temperature on surface tension of liquid.

Experiment (3)

Determine the viscosity of a given liquid by Ostwald's viscometer.

Apparatus:

Ostwald's viscometer and stop watch.

Chemicals:

Benzene, acetone or any liquid.

Theory:

It is a general property of fluids (liquids and gases) to flow under an applied force. When a liquid through a tube, a layer of the liquid in contact with the wall of the tube remains stationary whereas the layer in the center has the highest velocity. The velocity of different intermediate levels increases continuously with distance from the wall of the tube to the center. Thus there is a movement of different layer over one another in the direction of flow. This relative movement of different layers experiences a frictional force and each layer experiences a frictional force and each layer exerts a drag on the next layer in backward direction. This internal friction or resistance which retards the flow of the liquid is known as viscosity.

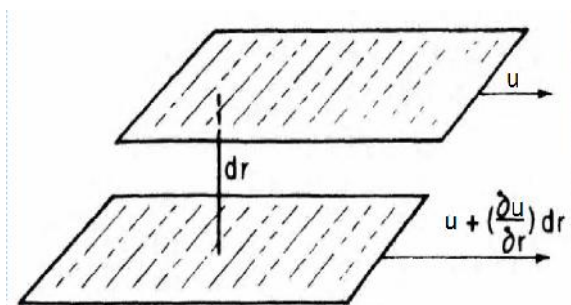


Figure. A

If two layer of a liquid are dr meters apart and have a velocity difference $du \text{ m s}^{-1}$, which shown in Fig.(a) then a force F acting per unit area of contact $A \text{ m}^2$ is given by

The frictional force F , resisting the relative motion of any two adjacent layers, is proportional to A , the area of the interface between them, and to du/dr , the velocity gradient between them. This is Newton's Law of

Viscous Flow,

$$F \propto A \, du / dr \quad = \quad \eta \, A \, du / dr$$

η is the coefficient of viscosity and is defined as the force per unit area required to maintain unit different of velocity between two parallel layers in the liquid, unit distance apart. It is expressed as dynes cm^{-2} .

The common unit of η are poise, centipoises (1/100 poise) and millipoise (1/1000).

The C.G.S unit of η is $(\text{g.cm}^{-1} \text{ sec}^{-1})$.

Factors affecting viscosity of liquids:

- 1) The viscosity of liquid depends upon the strength of intermolecular forces. If the intermolecular force of attraction is more, the viscosity will be also more.
- 2) The viscosity of liquids increase by increase molecular weight of a liquid.
- 3) Polar compound have more viscosity.
- 4) The viscosity of liquids increase by the presence of solute in it.
- 5) Liquid with large branch chain molecules have higher viscosity.
- 6) An increase in temperature decreases the viscosity of liquids.
- 7) The increase in pressure increases the viscosity to small extent.

Measurement of viscosity

The common method used for the measurement of viscosity is the observation of flow of liquid through a capillary tube. Poisuille gave an expression for the viscosity of liquid on the basis of its flow through capillary tube as

$$\eta = \frac{\pi r^4 t}{8 P v l}$$

Where, η is viscosity, r is the radius of the capillary tube, t is the time required for the volume V of the liquid to flow through the length l , P is hydrostatic pressure on the liquid.

The simple method of comparison of the viscosities of two liquid is generally used. The viscosity of a liquid is measured with respect to other standard liquid, generally water. In this method the flow time of equal volumes of two liquids through the same viscometer is measured. The apparatus generally used for the measurement of viscosity is Ostwald's viscometer.

Ostwald's Viscosity

Poiseuill's apparatus modified by Ostwald is U-shape tube with two bulbs A and B and a sort of fine capillary CD. The volume of liquid within EC is allowed to pass through the fine capillary CD and time required to flow the liquid is noted down. Bulb B works as reservoir to collect liquid. The force driving the liquid through the capillary CD is equal to $h \times \rho \times g$, where h is the mean difference of height between the levels of the liquid in two limbs of the tube, ρ is the density of the liquid and g the gravitational constant. The force which oppose this flow depends on dimensions of the capillary and viscosity of liquid. Thus the time of flow of liquid from C to D in the capillary is directly proportional to the viscosity and inversely proportional to the driving force. Thus

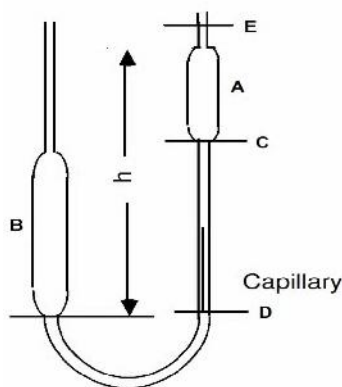


Fig.8 viscometer.

$$\text{For liquid 1, } T_1 \propto \frac{\eta_1}{h \rho_1 g}$$

$$\text{For liquid 2, } T_2 \propto \frac{\eta_2}{h \rho_2 g}$$

$$\frac{T_1}{T_2} = \frac{\eta_1 h \rho_2 g}{\eta_2 h \rho_1 g} = \frac{\eta_1 \rho_2}{\eta_2 \rho_1}$$

$$\eta_2 = \frac{T_2 \rho_2 \eta_1}{T_1 \rho_1}$$

If the absolute viscosity of one liquid is known, that other can be calculated by measuring T_1, T_2, ρ_1 and ρ_2 .

Procedure:

- 1) Wash and clean the viscometer with chromic acid and distilled water thoroughly. Rinse it with acetone and dry with drier.
- 2) Take 10 ml of distilled water put it in the viscometer.
- 3) Suck up distilled water up to the mark and keep a stop watch ready.
- 4) Let off liquid, start the stop watch and note down the time required to flow the water through the capillary tube.
- 5) Repeat it for 3 times and find out mean time (t_1).
- 6) Take out water, rinse and dry it with acetone.
- 7) Take 10 ml of benzene put it in the viscometer.
- 8) Suck up benzene and note down time.
- 9) Repeat it for 3 times and find out mean time (t_2).
- 10) Determine the density of benzene and water by using density bottle.

Calculation:

Calculate the viscosity of liquid (i.e. benzene) by using the formula.

$$\eta_2 = \frac{T_2 \rho_2 \eta_1}{T_1 \rho_1}$$

Viscosity of water (η_1) is 8.91×10^{-3} poise.

Experiment (4)

Determine the radius of a molecule by viscosity measurements.

Apparatus:

Ostwald's viscometer, stop watch, standard flask, etc.

Chemicals:

Sucrose solution (0.1M) and distilled water.

Theory:

The size of molecule can be determined by viscosity of its solution. According to Einstein's equation:

$$\frac{\eta}{\eta_o} = 1 + 2.5\phi$$

Where, η is the viscosity of solution, η_o is the viscosity of solvent and ϕ is the volume fraction of solute. This equation is based on the assumptions that the solute particles are rigid spherical bodies without any mutual attraction. The size of molecule must be more than the molecule of solvent but it should be sufficiently smaller so that it can pass through the capillary of viscometer. Then equation modified as

$$\frac{\eta}{\eta_o} - 1 = (\eta_r - 1) = 2.5 \left(\frac{4}{3} \pi r^3 \right) N_o C \times 10^{-3} = 6.3 \times 10^{21} r^3 C$$

Where, $\eta_r = \eta/\eta_0 = t/t_0$, t is flow time of solution and t_0 is flow time of solvent, r is radius of solute particle in cm, N_0 is Avogadro's number, C is concentration of solute in mole/litter. Thus when $(\eta_r - 1)$ is plotted against C , it will be a straight line passing through origin having a slope equal to $6.3 \times 10^{21} r^3$.

This experiment consists of the determination of viscosity of a series of sucrose solution in concentration range of 0.005 to 0.1 M.

Procedure:

- 1) Clean the viscometer with acetone and dry it.
- 2) Prepare 0.02, 0.04, 0.06 and 0.08 M solution from stock solution (0.1M).
- 3) Determine the flow time for each solution and also for distilled water.
- 4) Determine the relative viscosity of each sucrose solution.
- 5) Plot a graph $(\eta_r - 1)$ vs C .

Calculation:

From the straight line graph determine the slope and calculate the radius of the sucrose molecule by using following equation:

$$r = \left(\frac{\text{Slope}}{6.3 \times 10^{21}} \right)^{1/3}$$

Then convert r in cm to Å°.

Experiment (5)

Determine the molecular weight of a high polymer by viscosity measurements e.g. (polystyrene).

Apparatus:

Ostwald's viscometer, density bottle, pipette and stop watch.

Chemicals:

Polystyrene, acetone and distilled water.

Theory:

The average molecular weight of a polymer can be determined by simple viscosity measurement and certain qualitative conclusions can be drawn about the general form of macromolecules in solution. The viscosity of high polymer solution depends on the size and shape of the molecule in solution. The measurement of viscosity is a useful method in the study of polymer configuration.

The method involves the preparation of a series of the polymer solutions of different concentrations in a suitable solvent and the measurement of their viscosity by Ostwald's viscometer. If the absolute viscosity of the solution is η and that of the solvent is η_0 the relative viscosity is given by $\eta_r = \eta / \eta_0$

If the flow times for solution and solvent are t and t_0 , then

$$\eta_r = t / t_0 = \eta / \eta_0$$

Provided the densities of solution and solvents are very close. Since the polymer solutions used in the experiment are very dilute, their densities will be approximately equal to that of solvent.

$$\therefore \text{Relative viscosity, } \eta_r = \frac{t}{t_0} = \frac{\eta}{\eta_0}$$

The specific viscosity $\eta_{sp} = (\eta_r - 1)$

Then the reduced viscosity will be given by

$$\eta_{red} = \frac{\eta_{sp}}{C}$$

Where, C is concentration of polymer in gm/100 ml of solvent.

When the quantity η_{sp}/C for different solutions is plotted against concentration C, a straight line will be obtained which on extrapolation to zero concentration gives the limiting viscosity $[\eta]$ which is related to the molecular weight of polymer by Standinger equation as :

$$[\eta] = KM^a$$

Where, M is molecular weight of the polymer, K and a are the constants depend upon the polymer and solvent at a particular temperature.

The values of K and a for some polymer – solvent systems are given in table (1) below at 25°C.

Polymer	Solvent	K	a
Polystyrene	Toluene	3.7×10^{-4}	0.62
Polyisobutylene	Toluene	3.6×10^{-4}	0.64
Polyvinyl alcohol	Distilled water	2.0×10^{-4}	0.76
Cellulose	Acetone	1.49×10^{-4}	0.82

Procedure:

1. Rinse viscometer with distilled water and then with acetone.
2. Prepare a stock solution (20 mg/ml) of polystyrene in toluene by weighing out 5.000 g of polystyrene, transferring it to a 250 ml volumetric flask and dissolving in toluene.
3. From stock solution, prepare 16, 12, 8 and 4 mg/ml in 100 ml volumetric flask and diluting with toluene up to the mark and keep them at same thermostat.
4. Determine the time flow of solvent.
5. Determine the time flow of each solution.

Calculation:

Calculate first the relative viscosity $\eta_r = t/t_0$ and then specific viscosity

$\eta_{sp} = (\eta_r - 1)$ for each solution. Then calculate the reduced viscosity η_{sp}/C , plot, η_{sp}/C versus C . hence find out the intrinsic viscosity $[\eta]$. By referring the values of K and from table for a given polymer, determine its average molecular weight.

Experiment (6)

Determine the specific and molar refraction of a given liquid by Abbe refractometer.

Apparatus:

Abbe Refractometer, dropper, cotton wool and density bottle.

Chemicals:

Alcohol or acetone and given liquid (Benzene)

Theory:

When a beam of light passes from rare to denser medium such as from air to a glass or liquid, it bends towards the normal at the interface. This phenomenon is known as refraction. According to Snell's law of refraction the ratio of the sine of the angle of incidence and that of refraction is constant and is called as the refractive index of liquid. The refractive index (n) of the liquid is given by

$$n = \frac{\sin i}{\sin r}$$

Where, i is the angle of incidence and r is the angle of refraction.

The refraction index of a medium is also defined as the ratio of the velocity of light in a vacuum to its velocity in given medium. Refractive index of the medium is always greater than one.

Refractive index depends upon temperature and concentration. The refractive index decreases with increase in temperature.

However, the specific refraction defined by the following equation is independent of temperature:

$$r = \frac{n^2 - 1}{n^2 + 2} \times \frac{1}{\rho}$$

Where, r is the specific refraction, n is the refractive index and ρ is the density of liquid. The specific refraction is independent of temperature because the change in the density of liquid.

Molar refraction or molecular refractivity of a substance is the product of specific refraction and molecular weight of the substance. Thus, the molecular refraction given by

$$[R] = \frac{n^2 - 1}{n^2 + 2} \times \frac{M}{\rho}$$

Where, M is the molecular weight of the substance and R is the molar refraction.

The molar refraction is additive and constitutive property. Each atom in a compound has definite contribution to the molar refraction of compound. The values of molar refraction are used in the determination of molecular structure.

Procedure:

- 1) Place the refractometer on a table near a window so that sufficient light reaches to prism.
- 2) Open the prism box by turning the lock nut. Clean the faces of both prisms with help of cotton wool and alcohol or acetone and close the prism box after drying.
- 3) Introduce few drops of liquid (Benzene) in the prism through the small hole on the prism box, by means of dropper. A film of liquid will be enclosed between the two prisms.
- 4) Focus the telescope by rotating the eye piece and adjust the mirror to reflect maximum light into the prism box.
- 5) Move the prism box backward and forward until a clear boundary between the light and dark regions appear.
- 6) Rotate the prism box until get the sharp boundary line.
- 7) Read the refractive index directly on the scale. Repeat the readings at least three times and take the mean.
- 8) Determine density of the liquid by using density bottle.

Calculation:

- i) Determination of specific refraction (r).

$$r = \frac{n^2 - 1}{n^2 + 2} \times \frac{1}{\rho}$$

- ii) Determination of molar refraction (R).

$$[R] = \frac{n^2 - 1}{n^2 + 2} \times \frac{M}{\rho}$$

Experiment (7)

Determine molecular weight by boiling point elevation

Apparatus:

Beaker, capillary tube, test tube, thermometer, burner and rubber band.

Chemicals:

Paraffin oil and unknown liquid.

Theory:

The boiling point of a liquid is the temperature at which its vapour pressure becomes equal to the atmospheric pressure.

This experiment demonstrates the use of colligative properties. The goal is to measure the molecular weight of a non-volatile solute by determining the concentration dependence of the boiling point elevation of a solution. The solvent used must be one of the compounds commonly referred to as volatile; that is, it must have an appreciable vapor pressure. One of the several useful aspects of colligative properties is the fact that the vapor pressure of volatile solvents is lowered when a non-volatile solute is used to make a solution. The difference between the boiling points of solution and pure solvent at a certain constant pressure is known as the elevation of boiling points of the solution. The result is that such a solution will necessarily have a higher boiling point than that of the pure solvent. The higher boiling point is due to the fact that a higher temperature is needed in the presence of the non-volatile solute, which is not making any contribution to the solution's vapor pressure, in order to cause the volatile component of the solution, the solvent, to exert one atmosphere of pressure. It must

be remembered that the boiling point elevation being investigated in this experiment is a property of the solution as a whole and, for ideal dilute solutions, is directly proportional to the solute concentration as shown in Equation

$$T_b = m \cdot K_b$$

Where, **m** is the solution molality and **K_b** is the boiling point elevation constant which is a function of the solvent not the solute. The value of **T_b** is the boiling point of the solution minus that of the pure solvent, **T_b^{*}**.

Table 2: boiling point elevation constants

Solvent	Boiling Point, T_b^* (deg C at 760 torr)	K_b (molal / deg @ 1 atm)
Acetone	56.0	1.71
Benzene	80.2	2.53
Bromobenzene	155.8	6.20
Chloroform	60.2	3.63
Ethanol	78.3	1.22
Ethyl ether	34.4	2.02
Methanol	64.7	0.83
Water	100.0	0.51

Factors affecting boiling point:

1. Pressure

By increase pressure increases boiling point.

2. Molecular weight

By increasing molecular weight increases boiling point.

3. Structure of the molecule & intermolecular interactions

a. Branching

Branching compounds have lower boiling point due to increases in symmetry.

b. Polarity

Polar compounds have higher boiling point.

c. Van derWaals interactions

A compound which include Van derWaals interaction between their molecules have lower boiling point.

d. H-bonding

A compounds which include H-bond have high boiling point due to H-bond requires more energy to break down.

4. Impurities

A solution contain impurities have higher boiling point than the pure solvent.

Procedure:

1. Place 2 ml of the unknown liquid in a small test tube.
2. Immerse a capillary tube sealed at the other end in the liquid.
3. Insert thermometer with capillary tube in to small test tube which contain the unknown liquid or attach the outer tube to a thermometer by means of rubber band.
4. Put test tube in an oil bath.
5. Start heating with a burner until a rapid stream bubbles coming out of the capillary tube at this point record this temperature as the boiling point of the liquid.
6. Repeat same procedure determine boiling point of solution.

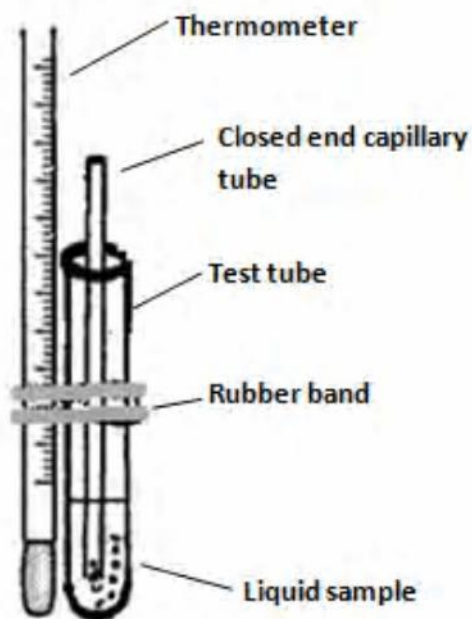


Fig. 9 measuring boiling point

Calculation:

Molecular weight can be calculated by using this equation:

$$\mathbf{T_b = m \cdot K_b}$$

$$T_b = T_{(\text{solution})} - T_{(\text{pure solvent})}$$

$$m = \text{no. of moles} / 1 \text{ kg}$$

$$K_b = \text{molal constant}$$

Experiment (8)

Determine Molecular Weight by the Dumas Method

Apparatus:

Conical flask, heater, beaker (water bath), aluminum foil and electronic balance.

Chemicals:

Unknown volatile liquid and water.

Theory:

One of the early methods for the determination of the molar mass of volatile substances was through the measurement of the density of the vapour of the substance. The method is reliable and convenient and is still employed in some situations. In this approach, the sample is added to a small flask, the flask is heated and as the sample evaporates, the air is swept out of the container. Then flask is cooled again, and the mass of liquid which condenses must be equal to the mass of vapor that filled the flask in the previous step. A little skill is required to judge the point at which the flask is just filled with sample vapour.

The combined gas law is given by the equation ;

$$p V = n R T, \quad (1)$$

where p is the pressure of the gas in atmospheres, V is the volume of the gas sample in liters, n is the number of moles of gas present, T is the temperature of the sample in Kelvin, and R is the empirically determined quantity known as the gas law constant which has the value of $0.0821 \text{ L atm mole}^{-1} \text{ deg}^{-1}$. This relationship

describes very well the behaviour of gases at ordinary pressures and moderate temperatures . In this experiment we rearrange the original combined gas law into a form more convenient for our calculations. Recall that the number of moles of a substance is equal to the mass of the substance divided by the mass of a mole of that substance :

$$n = \text{wt} / M, \quad (2)$$

Where wt represent the mass of the sample and M is the molar mass of the substance .Substituting this relationship into the combined gas law :

$$pV = (\text{wt}/M) RT \quad (3)$$

And rearranging to isolate the molar mass yields

$$M = (\text{wt} R T) / (p V) \quad (4)$$

You will recall that the ratio of mass to volume (wt/V) is commonly known as density .

Thus equation 4 may be rearranged to :

$$M = (\text{wt}/ V) (R T / p) \quad (5)$$

This is sometimes called the vapour density form of the combined gas law. The basic outline of this experiment is to add a small amount of a liquid sample to a small pre-weighed flask. The flask is then submerged into a boiling water bath. As the sample evaporates, the air is swept out of the flask, and we finally have a flask containing only the vapor of the unknown substance. If at that point the flask is cooled, the vapors will condensed and their mass may be determined by reweighing the flask. One may repeat the process and obtain an average of replicate measurements. Subsequent measurements are the made to determine the

volume of the flask, the temperature of the boiling water bath, and the prevailing atmospheric pressure. Those values and equation 5 are used to calculate the molar mass of the unknown liquid .

Procedure:

- 1) Determine the mass of the DRY flask to the nearest milligram.
- 2) Add about 5 mL of your unknown to the flask. Cut a small square of aluminum foil and wrap over the top to the flask. Make a small hole in the foil with a needle.
- 3) Immerse the flask in the boiling distilled water bath using a clamp and ring stand. Be sure the flask is submerged at least to the neck.
- 4) Heat the flask until you no longer see a Schlieren pattern emerging from the hole in the foil. Schlieren patterns are like the watery lines seen rising from a heated surface .Remove the flask when the pattern disappears. The flask should contain no liquid at this point. (Some people find that holding a paper towel or shiny surface over the hole can be helpful. When vapor no longer condenses on the towel or shiny surface, vapor is no longer emerging and no liquid should remain in the flask).
- 5) Cool the flask to room temperature and the vapors will condense into a small amount of liquid .
- 6) Dry the exterior of the flask with a paper towel and weigh the flask and contents to the nearest milligram. Remove the foil just immediately before weighing .
- 7) Repeat the vaporization and condensation steps (2-6) twice more so that you have three values for the mass of the condensed vapor .

- 8) Obtain the atmospheric pressure from the barometer in the laboratory .
- 9) Determine the volume of the flask by filling it completely with water and then measuring the volume of water contained in the flask with a large graduated cylinder.

The temperature of the boiling water bath can be interpolated from the following

Table (3) :

Pressure (mmHg)	735	740	745	750	755	760
Boiling Point (°C)	99.07	99.26	99.94	99.63	99.82	100.00

- 11) From the average mass of condensed liquid and the temperature, volume and pressure data, calculate the molar mass of your unknown liquid.

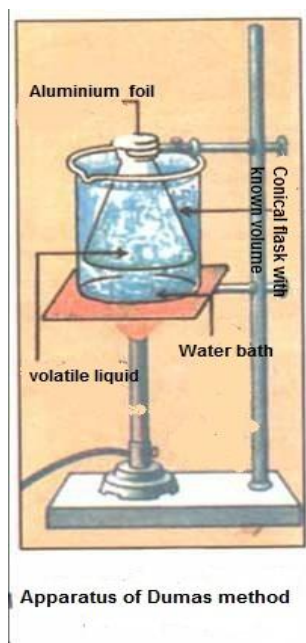


Fig. 10 Apparatus of Dumas method

Calculation:

The equation 5 is used to calculate the molar mass of the unknown liquid .

$$M = (wt/ V) (R T / p)$$

M is molar mass (molecular weight).

Wt is weight of unknown liquid

V is volume of conical flask

R is 0.082 L atm mol⁻¹

T is boiling point temperature of water bath in Kelvin

P is pressure

D is density of unknown liquid (0.7894 gm/ml)

Experiment (9)

Determine the heat of solution of oxalic acid from solubility in water at different temperature.

Apparatus:

Four beakers, pipette, cotton or filter paper, water bath, electronic balance and oven.

Chemicals:

Oxalic acid and distilled water.

Theory:

Solubility is the property of a solid, liquid, or gaseous chemical substance called solid to dissolve in liquid solvent to form a homogeneous solution of the solute in the solvent. The solubility of a substance fundamentally depends on the used solvent as well as on temperature and pressure. The extent of the solubility of a substance in a specific solvent is measured as the saturation concentration where adding more solute does not increase the concentration of the solution. Thus, in acquiring the solubility of oxalic acid, the equivalent weight of oxalic acid from the saturated sample of the solution is determined.

The Vant Hoff's equation also known as the Vukancic-Vukovis equation in chemical thermodynamics relate the change in temperature (T) to the given the enthalpy change (ΔH) for the process. It follows that

$$\ln (S/T) = \Delta H / RT^2$$

Final form of above equation will be

$$\log S = - \Delta H / 2.303RT$$

Where, S is the solubility (mol/kg), T is the temperature in (K) and ΔH is the heat of solution (J/mol).

Procedure:

1. Take four clean and dry beakers and label from 1 to 4.
2. Weight empty beakers and record their masses.
3. Prepare 50 ml of a saturated solution of oxalic acid at 50°C.
4. Pipette out 5 ml of saturated solution in beaker. To prevent sucking of small crystals into pipette along with solution a small piece of filter paper or cotton wrapped around the tip of pipette.
5. Weight beaker with solution and record it mass.
6. Put solution in oven to dry for (5-10) minutes at 100°C and weight it after cooled.
7. Repeat same procedure at 40°C, 30°C and 20°C.

Observation tabulate:

No.	Temperature (T°C)	Mass of empty beaker (g)	Mass of beaker and solution (g)	Mass of solution (g)	Mass of beaker and solid (g)	Mass of solid (g)	%Solubility (S)	log S
1	50							
2	40							
3	30							
4	20							

Calculation:

Mass of solid

$$1. \text{ Solubility} = \frac{\text{Mass of solid}}{\text{Mass of solution}} \times 100$$

Mass of solution

2. Plot log S against 1/T, $\Delta H = - \text{slope} \times 2.303R$

Experiment (10)

Determine the solubility of benzoic acid in water at different temperature and hence its heat of solution.

Apparatus:

Beakers, burette, pipette, filter paper, funnel and thermometer ..etc.

Chemicals:

Solid benzoic acid, 0.05N NaOH solution and phenolphthalein indicator.

Theory:

The process of dissolution of solid into liquid is usually accompanied with the absorption or evolution of heat. The heat of solution in the present experiment is the heat evolved or absorbed when one mole of the solid is dissolved in a solution which is already saturated. It differs from the heat of a solution at infinite dilution by an amount equivalent to the heat of dilution from saturation to infinite dilution.

The effect of temperature on solubility is given by vant Hoff's equation:

$$\frac{d \ln S}{dT} = \frac{\Delta H}{RT^2}$$

Where, S is solubility (strength) and ΔH , heat of solution.

On integration of the above equation, we have

$$\text{Log } S = \frac{-\Delta H}{2.303 RT}$$

Where, $R = 1.987 \text{ cal/mole}$.

Procedure:

- 1) Prepare the saturated solution of benzoic acid at 45°C, 35°C, 30°C, 25°C, 20°C and 15°C.
- 2) By taking 100 ml of distilled water in a beaker. Add increasing amount of benzoic acid with constant stirring until a small amount of solid remains undissolved.
- 3) Pipette out 10 ml of saturate solution in a conical flask. To prevent sucking of small crystal into the pipette along with the solution, a small piece of filter paper wrapped around the tip of pipette and fastened with thread. The filter paper should be removed before draining pipette.
- 4) Titrate this solution against 0.05N NaOH solution using ph.ph as an indicator.
- 5) Then determine the normality and strength of benzoic acid.

Calculation:

- i) Strength = Normality x Equivalent weight
- ii) Plot $\log S$ vs $1/T$. from the slope of the straight line calculate heat of solution ΔH as

$$\Delta H = - 2.303 \times R \times \text{Slope (cal/mole)}$$

Safety Guidelines in the Chemistry Laboratory

The chemistry laboratory is a safe place to work if you are aware of important safety rules and if you are careful. You must be responsible for your own safety and for the safety of others. The safety rules given here will protect you and others from harm in the lab. While carrying out procedures in any of the **ChemLabs**, notice the safety symbols and caution statements. The safety symbols are explained in the chart on the next page.












1. Always obtain your teacher's permission to begin a lab.
 2. Study the procedure. If you have questions, ask your teacher. Be sure you understand all safety symbols shown.
 3. Use the safety equipment provided for you. Goggles and a safety apron should be worn when any lab calls for using chemicals.
 4. When you are heating a test tube, always slant it so the mouth points away from you and others.
 5. Never eat or drink in the lab. Never inhale chemicals. Do not taste any substance or draw any material into your mouth.
 6. If you spill any chemical, wash it off immediately with water. Report the spill immediately to your teacher.
 7. Know the location and proper use of the fire extinguisher, safety shower, fire blanket, first aid kit, and fire alarm.
 8. Keep all materials away from open flames. Tie back long hair.
 9. If a fire should break out in the classroom, or if your clothing should catch fire, smother it with the fire blanket or a coat, or get under a safety shower. **NEVER RUN.**
 10. Report any accident or injury, no matter how small, to your teacher.
- Follow these procedures as you clean up your work area.
1. Turn off the water and gas. Disconnect electrical devices.
 2. Return materials to their places.
 3. Dispose of chemicals and other materials as directed by your teacher. Place broken glass and solid substances in the proper containers. Never discard materials in the sink.
 4. Clean your work area.
 5. Wash your hands thoroughly after working in the laboratory.






First Aid in the Laboratory

Injury	Safe Response
Burns	Apply cold water. Call your teacher immediately.
Cuts and bruises	Stop any bleeding by applying direct pressure. Cover cuts with a clean dressing. Apply cold compresses to bruises. Call your teacher immediately.
Fainting	Leave the person lying down. Loosen any tight clothing and keep crowds away. Call your teacher immediately.
Foreign matter in eye	Flush with plenty of water. Use eyewash bottle or fountain.
Poisoning	Note the suspected poisoning agent and call your teacher immediately.
Any spills on skin	Flush with large amounts of water or use safety shower. Call your teacher immediately.

Safety Symbols

These safety symbols are used in laboratory and investigations in this book to indicate possible hazards. Learn the meaning of each symbol and refer to this page often. *Remember to wash your hands thoroughly after completing lab procedures.*

SAFETY SYMBOLS	HAZARD	EXAMPLES	PRECAUTION	REMEDY
DISPOSAL 	Special disposal procedures need to be followed.	certain chemicals, living organisms	Do not dispose of these materials in the sink or trash can.	Dispose of wastes as directed by your teacher.
BIOLOGICAL 	Organisms or other biological materials that might be harmful to humans	bacteria, fungi, blood, unpreserved tissues, plant materials	Avoid skin contact with these materials. Wear mask or gloves.	Notify your teacher if you suspect contact with material. Wash hands thoroughly.
EXTREME TEMPERATURE 	Objects that can burn skin by being too cold or too hot	boiling liquids, hot plates, dry ice, liquid nitrogen	Use proper protection when handling.	Go to your teacher for first aid.
SHARP OBJECT 	Use of tools or glassware that can easily puncture or slice skin	razor blades, pins, scalpels, pointed tools, dissecting probes, broken glass	Practice common-sense behavior and follow guidelines for use of the tool.	Go to your teacher for first aid.
FUME 	Possible danger to respiratory tract from fumes	ammonia, acetone, nail polish remover, heated sulfur, moth balls	Make sure there is good ventilation. Never smell fumes directly. Wear a mask.	Leave foul area and notify your teacher immediately.
ELECTRICAL 	Possible danger from electrical shock or burn	improper grounding, liquid spills, short circuits, exposed wires	Double-check setup with teacher. Check condition of wires and apparatus.	Do not attempt to fix electrical problems. Notify your teacher immediately.
IRRITANT 	Substances that can irritate the skin or mucous membranes of the respiratory tract	pollen, moth balls, steel wool, fiberglass, potassium permanganate	Wear dust mask and gloves. Practice extra care when handling these materials.	Go to your teacher for first aid.
CHEMICAL 	Chemicals that can react with and destroy tissue and other materials	bleaches such as hydrogen peroxide; acids such as sulfuric acid, hydrochloric acid; bases such as ammonia, sodium hydroxide	Wear goggles, gloves, and an apron.	Immediately flush the affected area with water and notify your teacher.
TOXIC 	Substance may be poisonous if touched, inhaled, or swallowed.	mercury, many metal compounds, iodine, poinsettia plant parts	Follow your teacher's instructions.	Always wash hands thoroughly after use. Go to your teacher for first aid.
FLAMMABLE 	Open flame may ignite flammable chemicals, loose clothing, or hair.	alcohol, kerosene, potassium permanganate, hair, clothing	Avoid open flames and heat when using flammable chemicals.	Notify your teacher immediately. Use fire safety equipment if applicable.
OPEN FLAME 	Open flame in use, may cause fire.	hair, clothing, paper, synthetic materials	Tie back hair and loose clothing. Follow teacher's instructions on lighting and extinguishing flames.	Always wash hands thoroughly after use. Go to your teacher for first aid.

	Eye Safety Proper eye protection should be worn at all times by anyone performing or observing science activities.		Clothing Protection This symbol appears when substances could stain or burn clothing.		Animal Safety This symbol appears when safety of animals and students must be ensured.		Radioactivity This symbol appears when radioactive materials are used.		Handwashing After the lab, wash hands with soap and water before removing goggles.
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Physical Constants		
Quantity	Symbol	Value
Atomic mass unit	amu	1.6605×10^{-27}
Avogadro's number	N	6.022×10^{23} particles/mole
Ideal gas constant	R	8.31 L·kPa/mol·K 0.0821 L·atm/mol·K 62.4 mm Hg·L/mol·K 62.4 torr·L/mol·K
Mass of an electron	m_e	9.109×10^{-31} kg 5.485799×10^{-4} amu
Mass of a neutron	m_n	1.67492×10^{-27} kg 1.008665 amu
Mass of a proton	m_p	1.6726×10^{-27} kg 1.007276 amu
Molar volume of ideal gas at STP	V	22.414 L/mol
Normal boiling point of water	T_b	373.15 K 100.0°C
Normal freezing point of water	T_f	273.15 K 0.00°C
Planck's constant	h	$6.6260693 \times 10^{-34}$ J·s
Speed of light in a vacuum	c	2.997925×10^8 m/s

Alphabetical Table of the Elements

Element	Symbol	Atomic number	Atomic mass	Element	Symbol	Atomic number	Atomic mass
Actinium	Ac	89	227.027 8*	Mendelevium	Md	101	258.098 6*
Aluminum	Al	13	26.981 539	Mercury	Hg	80	200.59
Americium	Am	95	243.061 4*	Molybdenum	Mo	42	95.94
Antimony	Sb	51	121.757	Neodymium	Nd	60	144.24
Argon	Ar	18	39.948	Neon	Ne	10	20.179 7
Arsenic	As	33	74.921 59	Neptunium	Np	93	237.048 2
Astatine	At	85	209.987 1*	Nickel	Ni	28	58.6934
Barium	Ba	56	137.327	Niobium	Nb	41	92 .906 38
Berkelium	Bk	97	247.070 3*	Nitrogen	N	7	14. 006 74
Beryllium	Be	4	9.012 182	Nobelium	No	102	259.100 9*
Bismuth	Bi	83	208.980 37	Osmium	Os	76	190.2
Bohrium	Bh	107	262*	Oxygen	O	8	15.999 4
Boron	B	5	10.811	Palladium	Pd	46	106.42
Bromine	Br	35	79.904	Phosphorus	P	15	30.973 762
Cadmium	Cd	48	112.411	Platinum	Pt	78	195.08
Calcium	Ca	20	40.078	Plutonium	Pu	94	244.064 2*
Californium	Cf	98	251.079 6*	Polonium	Po	84	208.982 4*
Carbon	C	6	12.011	Potassium	K	19	39.098 3
Cerium	Ce	58	140.115	Praseodymium	Pr	59	140.907 65
Cesium	Cs	55	132.905 43	Promethium	Pm	61	144.912 8*
Chlorine	Cl	17	35.452 7	Protactinium	Pa	91	231.035 88
Chromium	Cr	24	51.996 1	Radium	Ra	88	226.025 4
Cobalt	Co	27	58.933 20	Radon	Rn	86	222.017 6*
Copper	Cu	29	63.546	Rhenium	Rc	75	186.207
Curium	Cm	96	247.070 3*	Rhodium	Rh	45	102.905 50
Dubnium	Db	105	262*	Rubidium	Rb	37	85.467 8
Dysprosium	Dy	66	162.50	Ruthenium	Ru	44	101.07
Einsteinium	Es	99	252.082 8*	Rutherfordium	Rf	104	261*
Erbium	Er	68	167.26	Samarium	Sm	62	150.36
Europium	Eu	63	151.965	Scandium	Sc	21	44.955 910
Fermium	Fm	100	257.095 1*	Seaborgium	Sg	106	263*
Fluorine	F	9	18.998 403 2	Selenium	Se	34	78.96
Francium	Fr	87	223.019 7*	Silicon	Si	14	28.085 5
Gadolinium	Gd	64	157.25	Silver	Ag	47	107.868 2
Gallium	Ga	31	69.723	Sodium	Na	11	22.989 768
Germanium	Ge	32	72.61	Strontium	Sr	38	87.62
Gold	Au	79	196.966 54	Sulfur	S	16	32.066
Hafnium	Hf	72	178.49	Tantalum	Ta	73	180.947 9
Hassium	Hs	108	265*	Technetium	Tc	43	97.907 2*
Helium	He	2	4.002 602	Tellurium	Te	52	127.60
Holmium	Ho	67	164.930 32	Terbium	Tb	65	158.925 34
Hydrogen	H	1	1.007 94	Thallium	Tl	81	204.383 3
Indium	In	49	114.82	Thorium	Th	90	232.038 1
Iodine	I	53	126.904 47	Thulium	Tm	69	168.934 21
Iridium	Ir	77	192.22	Tin	Sn	50	118.710
Iron	Fe	26	55.847	Titanium	Ti	22	47.88
Krypton	Kr	36	83.80	Tungsten	W	74	183.85
Lanthanum	La	57	138.905 5	Uranium	U	92	238.028 9
Lawrencium	Lr	103	260.105 4*	Vanadium	V	23	50.941 5
Lead	Pb	82	207.2	Xenon	Xe	54	131.29
Lithium	Li	3	6.941	Ytterbium	Yb	70	173.04
Lutetium	Lu	71	174.967	Yttrium	Y	39	88.905 85
Magnesium	Mg	12	24.305 0	Zinc	Zn	30	65.39
Manganese	Mn	25	54.938 05	Zirconium	Zr	40	91.224
Meitnerium	Mt	109	266*				

* The mass of the isotope with the longest known half-life.

